The Physics potential of LHCb: CP violation and rare decays in the beauty sector at LHCb

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The Physics Potential of LHCb:

CP violation and rare decays in the beauty sector at LHC

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2. Methods
3. LHCb detector
4. Physics performances
5. Status and Conclusions

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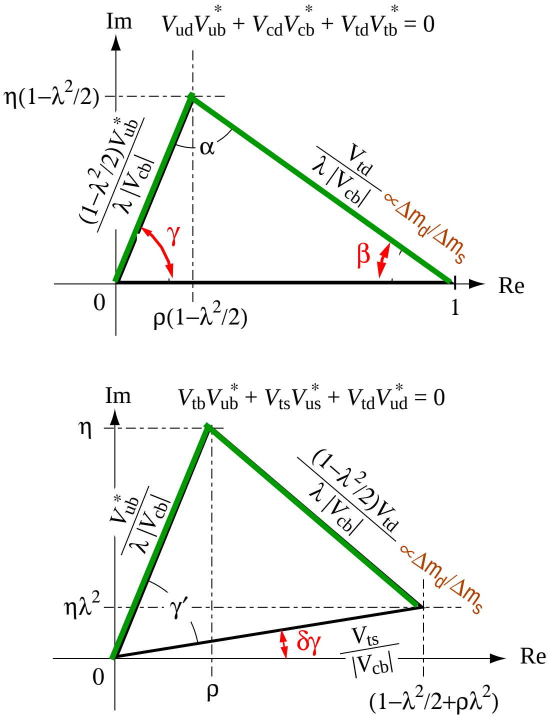
MOTIVATION

- **Standard Model accommodates CP violation through the CKM matrix.This mechanism has to be validated.**

  Unitarity property of the matrix → Unitarity Triangles (UT):



- Currently the UT is weakly constrained (ε, $|V_{ub}|$, $|V_{cb}|$, Δm_d)
- Will be improved in ~2005:
  - **Δm_s?** (HERA-b, CDF/D0)

  CP violation in the B_d system:
  - β (BaBar, Belle, CDF/D0, HERA-b)
  - α? (BaBar, Belle, HERA-b)
- Significant theoretical uncertainties on the length of the sides

- **LHCb will measure:**
  - CP violation in the B_s system
  - all phases: β, γ, $\delta\gamma$, $(\beta+\gamma)$,…
  - one side: Δm_s

  ➥ **Over-constrain the unitarity triangles.**
  Understand CP violation in the framework of the Standard Model.

MOTIVATION …

- **2nd motivation is related to the evolution of the Universe.**
  The disappearance of the antimatter component requires CP violation.
  But, the CP violation from the Standard Model is too small.

  ➥ **Additional sources of CP violation are needed.**
  They might find their origin in supersymmetric models

- **LHCb is a promising place to study new physics.**
  Complementary approach to ATLAS and CMS.

- **LHCb will measure:**
  - The phase β, γ using different decay modes.
  - Branching ratio of rare decays such as: $B_s \to \mu^+\mu^-$, $B_{d,s} \to K^{*0}\mu^+\mu^-$,…

These measurements couple with the unitarity checks of the CKM matrix will allow to pin down the details of new physics.

2.

Experimental methods to determine

β, γ, $(\beta+\gamma)$, $\delta\gamma$,…

Time dependent decay rate asymmetry

- $$A_{CP}(\tau) = \frac{\Gamma(B^0_{d,s} \to f_{CP})(\tau) - \Gamma(\overline{B}^0_{d,s} \to f_{CP})(\tau)}{\Gamma(B^0_{d,s} \to f_{CP})(\tau) + \Gamma(\overline{B}^0_{d,s} \to f_{CP})(\tau)} \neq 0 \Leftrightarrow \begin{cases} \text{CP Violation} \\ CP|B^0\rangle = |\overline{B}^0\rangle \\ CP|f_{CP}\rangle = \pm|f_{CP}\rangle \end{cases}$$

- $$A_{CP}(\tau) \equiv \begin{tikzcd} B^0 \arrow[rr, bend left] \arrow[r, bend right] & \overline{B}^0 \arrow[r, bend right] & f_{CP} \end{tikzcd} \equiv \pm\sin[\underbrace{2(\phi_M + \phi_D)}]\sin(\Delta m\tau)^{\dagger}$$

			Visible BR
$B^0_d \to J/\psi K_s$	2β		3.6×10^{-5}
$B^0_d \to \pi^+\pi^-$	$2\beta + 2\gamma$	$\left\lvert\frac{P}{T}\right\rvert, \delta_{P/T}$	0.7×10^{-5}
$B^0_s \to J/\psi\phi$	$2\delta\gamma$	$\left\lvert\frac{A(CP=+1)}{A(CP=-1)}\right\rvert, \delta_1, \Delta\Gamma_S$	5.4×10^{-5}

†. When more than one amplitude contributes to the decay: $A_{CP}(\tau) = A^{dir}_{f_{CP}}\cos(\Delta m\tau) + A^{mix}_{f_{CP}}\sin(\Delta m\tau)$

TIME DEPENDENT DECAY RATE ASYMMETRY…

- **When the final state is not a CP eigenstate:**

			Visible BR
$B_S^0 \to D_S^{\pm} K^{\mp}$	$-2\delta\gamma + \gamma$	$\left\|\frac{T_1}{T_2}\right\|, \delta_{T_1/T_2}$	0.9×10^{-5}
$B_d^0 \to D^{*\pm} \pi^{\mp}$	$2\beta + \gamma$	$\left\|\frac{T'_1}{T'_2}\right\|, \delta_{T'_1/T'_2}$	6.7×10^{-5}
$B_S^0 \to D_S^{-} \pi^{+}$		$\Delta m_s, \Delta\Gamma_s$	12×10^{-5}

OTHER METHODS…

- **Dalitz plot analysis:**

			Visible BR
$B_d^0 \to \rho\pi \to \pi^+\pi^-\pi^0$	$\beta+\gamma$	T^{-+}, T^{00}, P^{+-}, P^{-+}	5.5×10^{-5}

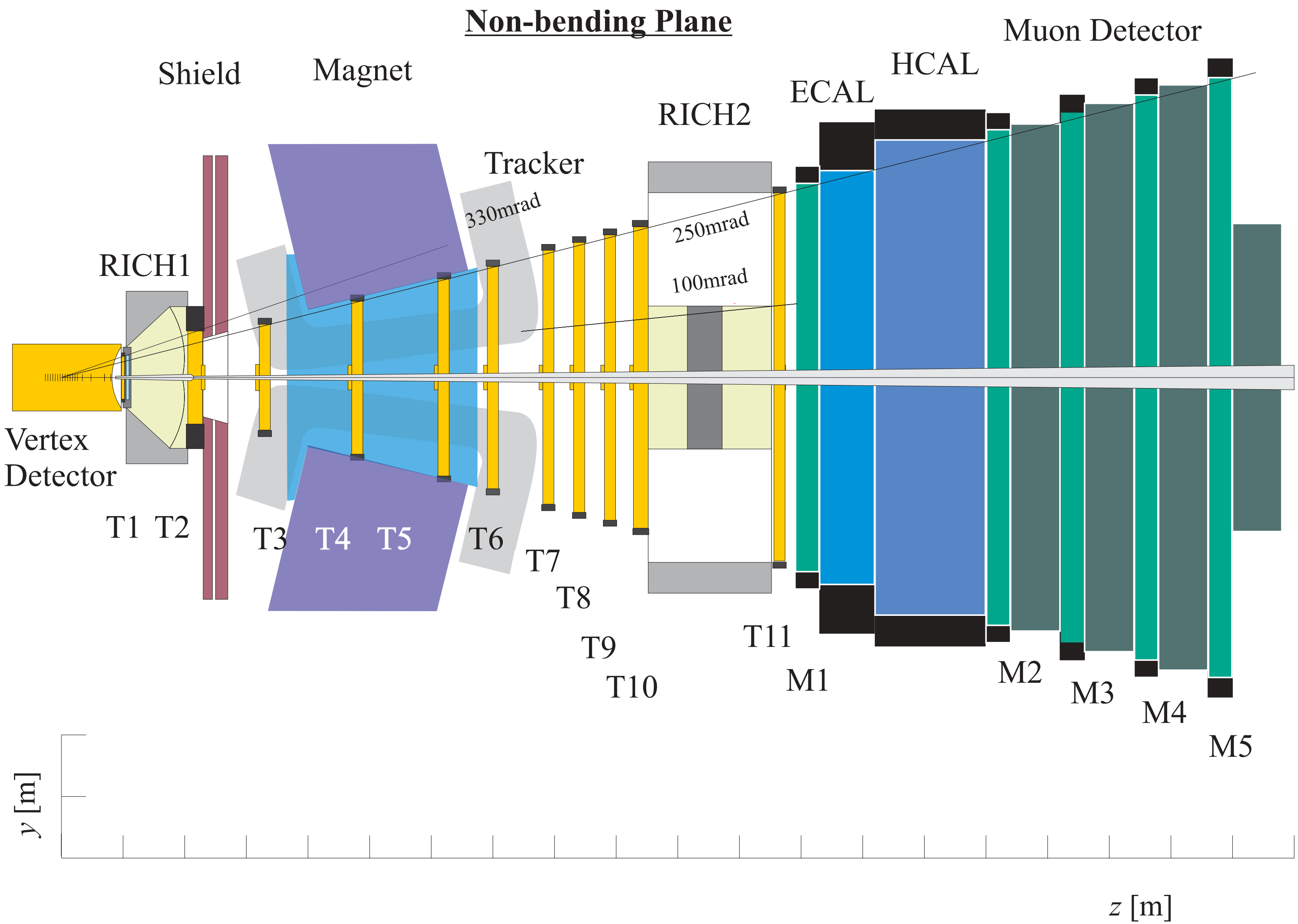
- **Branching ratio measurements:**

			Visible BR
$B_d^0 \to \begin{cases} \bar{D}^0 K^{*0} \\ D^0 K^{*0} \\ D_1 K^{*0} \end{cases}$ + c.c.	γ	δ_4	10^{-8}–10^{-7}

- **New strategies are proposed to measured γ. They are under evaluation.**

3.

LHCb detector...



Non-bending Plane
Shield
Magnet
Muon Detector
HCAL
ECAL
RICH2
Tracker
330mrad
250mrad
100mrad
RICH1
Vertex
Detector
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
M1
M2
M3
M4
M5
y [m]
z [m]

LHCb DETECTOR PERFORMANCES

- **Particle identification** [RICH]:
  - K/π separation $> 3\sigma$ in the momentum range of the experiment
- **Resolutions** [Vertex detector, Tracking chambers]:
  - Momentum $\approx 0.3\%$
  - Impact parameter $\approx 40\ \mu$m
  - Decay-time $\approx 0.03\ \tau$B (43 fs)
- **Tagging:**
  - Efficiency (K, e, μ) $\approx 40\%$
  - Dilution factor $\approx 40\%$

RUNNING CONDITIONS

Low Luminosity: 2×10^{32} cm^{-2}s^{-1}

- **Tunable locally although ATLAS and CMS work at high luminosity**
  - Ensures long physics programme
  - Guarantees physics results from the beginning of LHC

- **Clean event:**
  - ~0.3 interactions/BC

- **Highest statistics of B's ever collected:**
  - 4.5×10^{11} $B_d+\overline{B}_d$ produce per year
  - 1.3×10^{11} $B_s+\overline{B}_s$ produce per year

4.

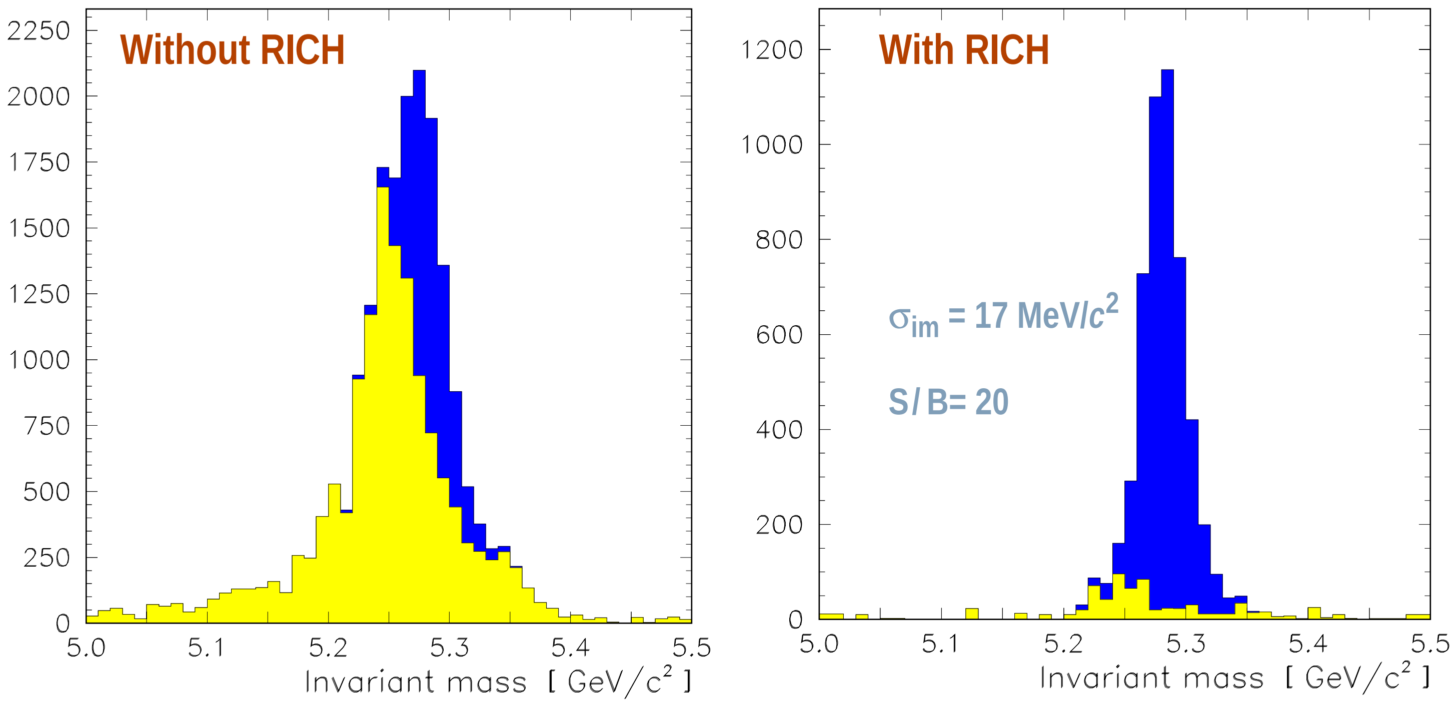
Physics performances…

$B_d \rightarrow \pi^+\pi^-$ $(\beta+\gamma)$

Importance of particle identification

Branching ratio: $B_d \rightarrow \pi^+\pi^- = 0.7\times10^{-5}, \rightarrow K^\pm\pi^\mp = 1.5\times10^{-5}$

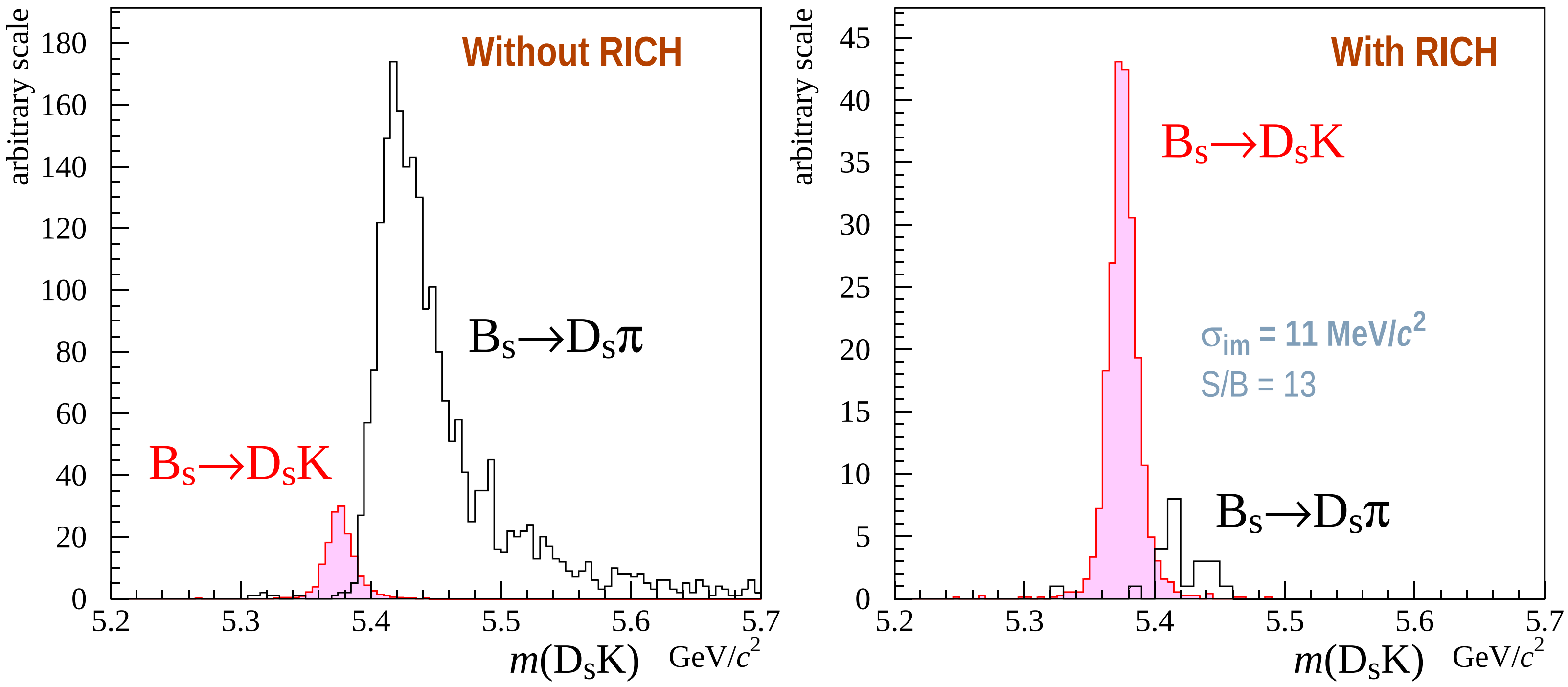
$B_s \rightarrow \mathbf{K}^+\mathbf{K}^- = 1.5\times10^{-5}, \rightarrow K^\pm\pi^\mp = 0.7\times10^{-5}$



$B_s \to D_sK$ $(\gamma - 2\delta\gamma)$

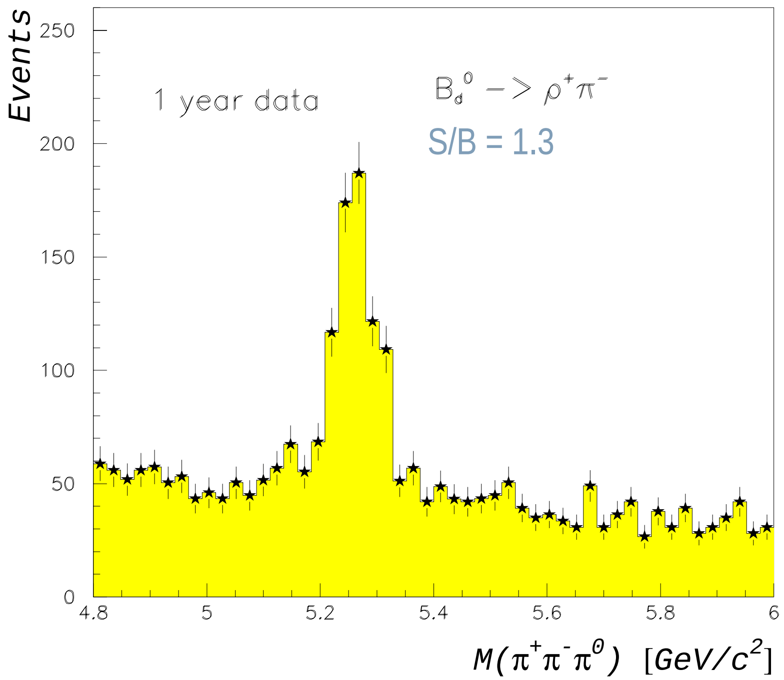
Major background: $B_s \to D_s\pi$ (No CP violation)

Importance of particle identification and mass resolution



$B_d \to \rho\pi \to \pi^+\pi^-\pi^0$ $(\beta+\gamma)$, |P|, |T|,...

Importance of π^0 reconstruction

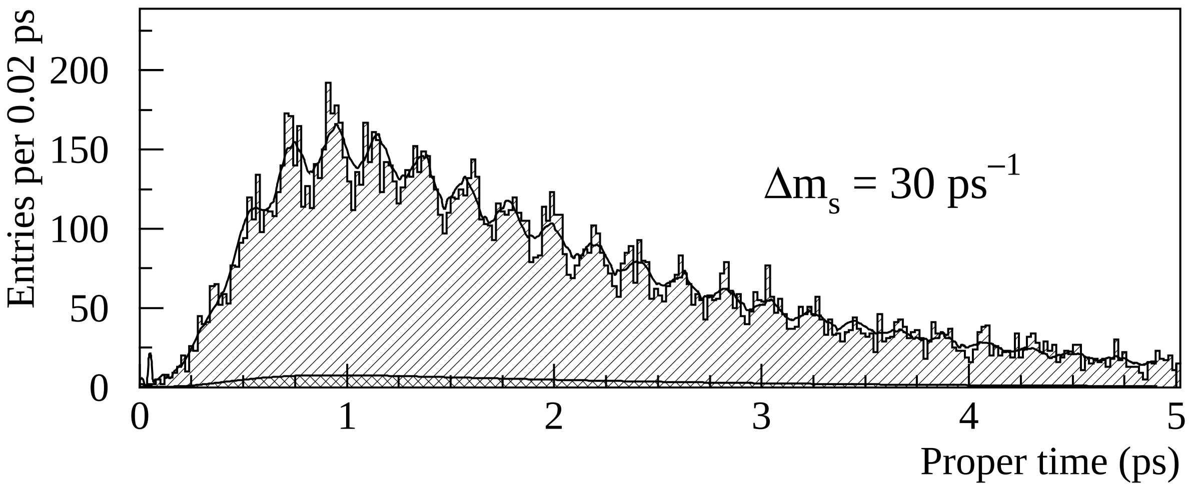


Events per year:

$B_d \to \rho^+\pi^-$	~1000	(Br 4.4×10^{-5})
$B_d \to \rho^-\pi^+$	~ 200	(Br 1.0×10^{-5})
$B_d \to \rho^0\pi^0$	~ 100	(Br 0.1×10^{-5})

$B_s \to D_s\pi$ (ΔM_s, $\Delta\Gamma_s$)

Importance of decay-time resolution



➥ **Measurement of Δm_s with a significance > 5, up to 48 ps^{-1}** (x_s=75)
Standard Model expectation: 14.3–26 ps^{-1}

SUMMARY OF THE PERFORMANCES

Sensitivity per year of data taking:

		LHCb Lum=2×10^{32}	
$B_d^0 \to J/\psi K_S$	$\sigma(\sin 2\beta)$	0.02	when $\beta = 20°$
$B_d^0 \to \pi^+\pi^-$	$\sigma(A^{dir})$	0.07	
	$\sigma(A^{mix})$	0.09	
	$\sigma(\beta+\gamma)$	~2°	If $\lvert P/T \rvert = 0.20\pm0.02$ when α=90° and δ=30°
$B_d^0 \to \rho\pi$	$\sigma(\beta+\gamma)$	2°–5°	Preliminary: Backg. not included in the fit Depends on the value of $\beta+\gamma$
$B_d^0 \to D^{*\pm}\pi^{\mp}$	$\sigma(2\beta+\gamma)$	~9°	when $\lvert 2\beta+\gamma \rvert < 25°$
$B_s^0 \to J/\psi\phi$	$\sigma(\delta\gamma)$	0.6°–1.4°	depends on the value of Δm_s SM expectation: ~1°
$B_s^0 \to D_s^{\pm} K^{\mp}$	$\sigma(\gamma-2\delta\gamma)$	6°–13°	Depends on the value of: • $\gamma-2\delta\gamma$ • strong phase shift difference
$B_d^0 \to D^0 K^{*0}$	$\sigma(\gamma)$	4°–19°	Depends on the value of: • γ • strong phase shift difference

$B_s^0 \to D_s^{\pm}\pi^{\mp}$	x_s reach	<75	Significance > 5
$B_s^0 \to \mu^+\mu^-$	$S/\sqrt{B}$	~6	SM expectation BR = 3.5×10^{-9}

$B_d^0 \to K^{*0}\gamma$	$\lvert V_{ts} \rvert$	26×10^3 evts.

5.

Status and conclusions…

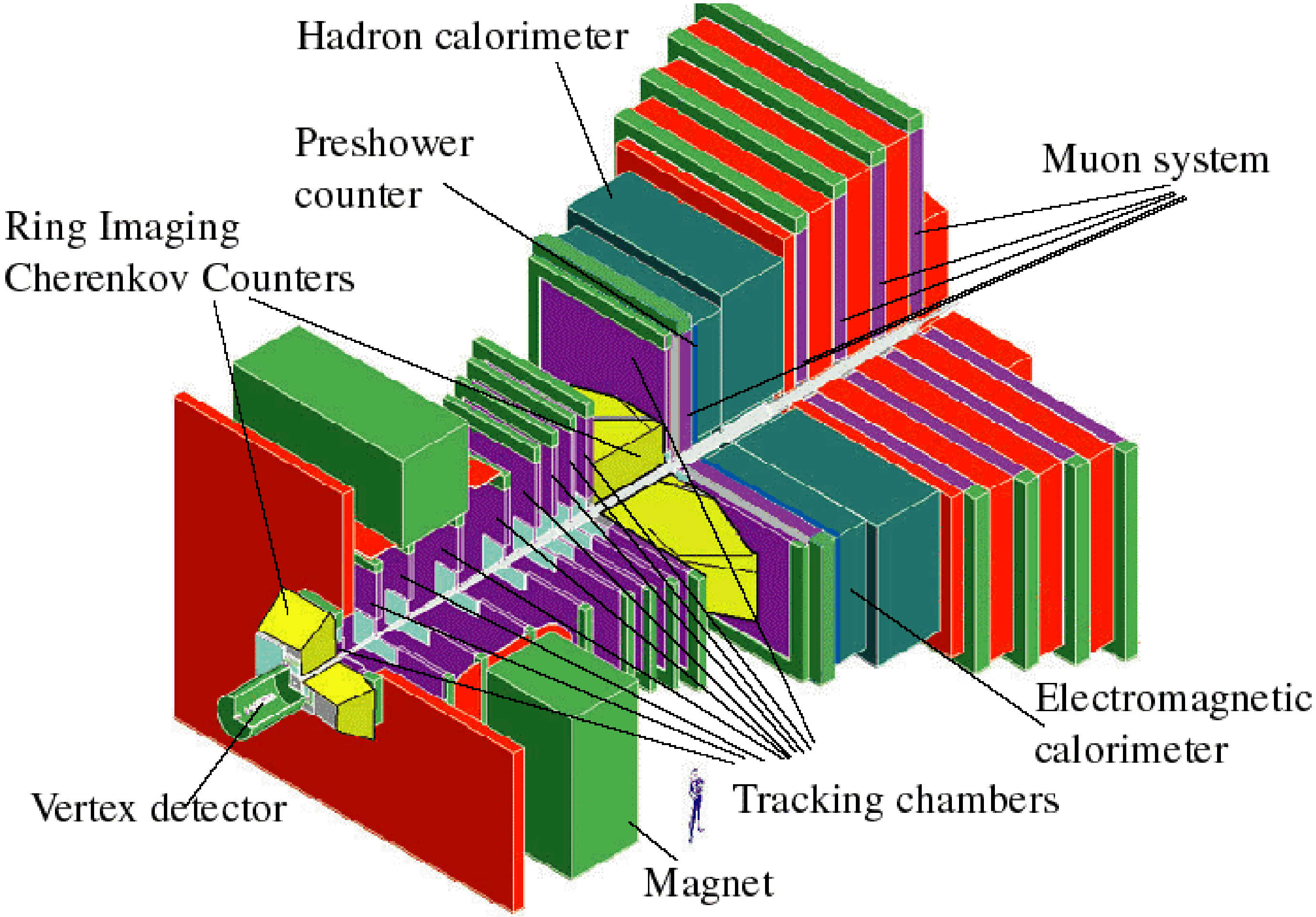
The *LHCb* Experiment

Brazil

USA

Finland

Ukraine



France

UK

Germany

Switzerland

Italy | Poland | PRC | Netherlands | Romania | Russia | Spain

STATUS AND PLANS

- Technical Proposal approved in September 98
- Preparing Technical Design Reports:

– Magnet	end 99	✓
– RICH – Calorimeter – Outer tracker – Muon – Vertex – Inner tracker – Trigger + DAQ	from now on to 2002	

- Construction: 2001–2003
- Ready for the first collision of the LHC

CONCLUSIONS

- LHCb is an opportunity to understand the CP violation
  in the framework of the Standard Model
  and BEYOND.

- LHCb fully exploit the physics from the beginning of the LHC